Testing of an on-board active suppression system for French mining conditions

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Synopsis

The French research institute, INERIS, requested the assistance of the CSIR's Division of Mining Technology in developing further precautionary measures against explosions in their collieries. In response to this approach, an on-board active suppression system was adapted to meet their mining requirements.

This system is used on tunnelling machines in Germany where the machine is positioned in the middle of the tunnel, which is therefore not much wider than the machine itself. With this configuration, the machine is never away from the tunnel face during the cutting cycle. As a result, the possible volume in front of the machine of combustible gas requiring suppression is less than 50 m^3.

In South Africa this technology has been adapted to suit a two-cut mining method which entails greater distances from the face and thus much larger volumes of methane mixtures requiring suppression. The particular configuration of the Explo-Stop® system being investigated required the suppression of possible methane ignition volumes of up to 180 m^3 of a 9% per volume methane/air mixture. The volume is a consequence of the large cross-sectional area of French underground workings and of the two-cut mining method used in France. In order to take the second cut in the coal seam, the machine is pulled back a maximum distance of 4 m, leaving an air pocket in which gas can accumulate. The machine-mounted system is required to effectively suppress any flame ignited by such a large accumulated volume of methane.

The results of the protocol tests done at Kloppersbos showed that the system was capable of suppressing all simulated methane ignitions for the prescribed conditions. This was achieved with a temperature increase of less than a 100°C at the operator's position and without any flame being detected at this position.

Introduction

The major source of methane ignitions within the coal-winning face is the action of the cutting picks of the tunnelling machine on small quartz and sandstone inclusions in the coal seam. To help reduce the risk of such ignitions, the picks are cooled with water sprays, methane detectors are mounted at the face to monitor methane concentrations, and ventilation is used to prevent methane build-up at the face. Even with these and other precautions in place, however, ignitions do still occur.

The Explo-Stop® active suppression system is used in conjunction with 'traditional' methods of explosion prevention. This system detects a methane ignition and then prevents it from developing into a methane explosion. This, in turn, prevents the dispersal of coal dust into the air and thus stops the methane explosion from escalating into a full-scale coal dust explosion. The objective of the system is to detect and extinguish the methane explosion before it reaches the position of the operator of the tunnelling machine.

Once an ignition has been detected, ultraviolet sensors specifically designed to respond at the frequency of the electromagnetic radiation generated by burning methane trigger the system. Within milliseconds, the detonation valves of the High Rate of Discharge (HDR) bottles open, releasing their contents of extinguishant powder and creating a fire barrier, thus preventing the flame from spreading any further.

Background

The main aim of this project was to verify the effectiveness of the Explo-Stop® system for French mining conditions. The Joy 14CM9 machine (for low seam conditions) had been tested previously, in South Africa. As with the Joy machine, the French mining method involves a two-cut process, with the machine having to move out of the shoulder area before taking the second cut, thus generating a large air pocket in front of the machine in which methane can build up.

The mining cycle used in France represented a new set of test conditions for Explo-Stop® on tunnelling machines. These

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 SA ISSN 0038–223X/3.00 + 0.00. Paper received Dec. 2000; revised paper received Jul. 2001.

included medium-to-high seam heights (for the two-cut mining method) and a non-symmetrical roof, which posed a further challenge with the configuration of the system.

These tests were carried out in accordance with a protocol developed by the CSIR for testing machine-mounted systems (Du Plessis *et al*., 1999). The Safety in Mines Research Advisory Committee had accepted a similar protocol for the tests on the Joy 14CM9. INERIS of France also accepted this protocol in accordance with French regulations, thus permitting the use of the system underground once qualified.

The objectives of the project laid down acceptance criteria in accordance with which the results of the tests would be either accepted or rejected, and the tests themselves either passed or failed.

The protocol stipulates the following acceptance criteria:

- The flame should not propagate along the tunnel in line with the operator's position—so that the operator is not exposed to any direct flame
- The temperature increase at the operator's position should not exceed human tolerance levels (in this case 100°C for less than half a second)
- Both the dynamic and static pressures measured should be within human tolerance limits
- There should be no false triggering of the system due to other equipment being used underground
- The system should be up and running again within 8 hours of a detonation.

System description

The Explo-Stop® system consists of three main components:

- The control electronics
- The ultraviolet sensor units
- The high rate of discharge (HDR) assemblies.

The control electronics are connected to the peripheral sensor units and HRD assemblies, constantly monitoring the connections so that the system will always be functional when required.

The ultraviolet sensor units are strategically placed to monitor the entire area of the cutting drum for any methane ignition. These sensor units are specifically designed to react only to certain ultraviolet light wavelengths specific to burning methane, thus reducing the risk of a false ignition.

The HRD assemblies are configured for the particular conditions of the machine used for tunnelling, the cross-sectional area of the tunnel, and the method of coal extraction being applied. They are configured to ensure the correct powder distribution for successfully extinguishing the explosion.

Test equipment

A test tunnel had previously been erected at the CSIR's Kloppersbos Research Facility for the purpose of testing machine-mounted active suppression systems. This tunnel was modified to simulate the dimensions of the French mine workings and a full-scale model of the DOSCO 1300H machine was procured for test purposes.

Test tunnel

The Kloppersbos tunnel is 20 m long and 7 m wide, with a variable height of 2 to 6 m. It has a cement floor and springs along both sides, on the outside, supporting and guiding it. For the case of an unsuppressed explosion, the tunnel is able to lift up to 140 mm off its base to provide an alternative escape route for the expanding gases.

For the full-face conditions, the cross-sectional area was approximately 23,3 m^2. Later, after the full-face tests had been completed, a 4-m-long shoulder was built into the right-hand front corner of the tunnel to simulate the two-cut scenario.

To approximate French conditions, an additional incline was erected inside the roof of the tunnel with the height of the tunnel being adjusted to 4,2 m at the highest (top left) side, sloping down to 2,5 m on the lowest side, from left to right, at an angle of 15 degrees.

Methane supply

A network of pipes connects the methane gas supply station to the tunnel. Methane is fed into the tunnel through this network and by means of flat spray nozzles. The flow rate of the gas is controlled through quick-closing valves.

Before the tests commence, a plastic membrane is placed behind the position of the machine-mounted system, with the purpose of containing the methane/air mixture during mixing. A fan is used to assist in the mixing process and to ensure a uniform mixture. The cutting drum on the model rotates during ignition; this increases the reaction and speed of the flame (see Figure 1 which shows the plastic membrane forming the methane chamber at the front of the tunnel).

Monitoring of the methane mixture

Also placed in the front section of the tunnel is an intricate pipe network connected to the device for sampling the methane mixture. While the methane is being mixed into the contained air volume, samples of the mixture are taken continuously to monitor the methane concentration. Once the readings from the various sampling points throughout the tunnel are uniformly at the desired concentration, the mixture can be ignited.

Infrared sensors

In order to measure the propagation of the flame along the

Figure 1—Plastic membrane in position

tunnel, infra-red sensors are placed in four rows along the walls and roof of the tunnel. These sensors are silicon photovoltaic cells which react to the infra-red light emitted during burning. They are placed as follows:

- One row along the right-hand wall (right flame-RF)
- One row along the left-hand wall (left flame-LF)
- Two rows in the roof. (top left flame-TLF and top right flame-TRF).

In each row, the first sensor is placed 1 m from the front face of the tunnel, after which each row contains a further 18 sensors, spaced 1 m apart, extending right to the back of the 20-m tunnel. Figure 2 shows a set of flame sensor data (operator side of tunnel).

The data are given in the form of a bar chart, allowing immediate determination of the maximum intensities measured by the flame sensors along the length of the tunnel. This also allows easy determination of the length of the flame before it was completely suppressed. In this case the flame extended to a maximum of 7 m as measured by the top right-hand row of sensors.

Pressure sensors

One static pressure reading is taken at the position of the operator's cab. A piezoelectric sensor is used to measure the absolute (gauge) pressure at this position.

One dynamic pressure sensor is mounted 2 m from the open end of the tunnel and this is used to measure the wind force as the pressure wave from the explosion moves through the tunnel.

Temperature sensor

A thermocouple is placed at the operator's cab to measure the temperature rise to which the operator would be exposed. The temperature reading is measured as an increase, from ambient, with the ambient temperature being designated as 0V. Although this sensor is constructed of a relatively fine bimetallic wire, there is a slight lag in the temperature measurement. For this reason the temperatures analysed represented temperature rises rather than absolute temperature values. Moreover, unfortunately, the thermocouple also cools down rather slowly, mostly by convection with the surrounding air. It is therefore assumed that after the temperature has peaked, the surrounding temperature returns immediately to ambient, although the thermocouple takes a while to cool down. Figure 3 shows an example of the temperature charts compiled from the data generated from the measurements of the thermocouple temperature sensor.

The graph shows that over the 2-second sampling period, the temperature at the operator's cab position rises from around 0 to a maximum of just above 10°C (where 0 is equivalent to the ambient temperature).

Photographic record

A video camera was attached to the roof of the tunnel, 1 m from the open end, to capture a visual record of the tests.

Data-acquisition system

The data-acquisition system was custom-built and has 128 input channels, each of which sample simultaneously at a rate of 30 kHz for a period of 2 seconds. For these tests, 75 of these channels were used. The data are stored on the system's hard drive, and are available immediately after testing.

Protocol tests

In accordance with the protocol (Du Plessis, 1998), the test sequence was carried out in order of ascending difficulty. Three main placements of the machine inside the tunnel were tested, as well as sub-conditions for the placements of the boom (and thus ignition) for these machine positions, and, of course, the various methane concentrations.

The three main placements were:

- *Full-face*—to simulate the position of the machine at the beginning of the first cut (see Figure 4)
- *In-shoulder*—to simulate the position in which the machine has completed the first cut but is still within the confines of the cavity, with the shoulder adjacent to it (see Figure 5)
- *Out-shoulder*—to simulate the position in which the machine has moved back out of the 4-m-shoulder area and is preparing to start the second cut (leaving a large cavity exposed next to the shoulder in which a build-up of methane could occur) (see Figure 6).

For these three main placements, the following sub-conditions were tested for the different boom positions of the machine (in this order):

- Bottom left (BL)
- Bottom right (BR)
- Centre face (C)
- Top left (TL)
- Top right (TR).

In order of ascending difficulty, for the sub-conditions, first a less potent 7,5% (methane/air concentration) explosion was carried out. Thereafter, the 9,0% explosions

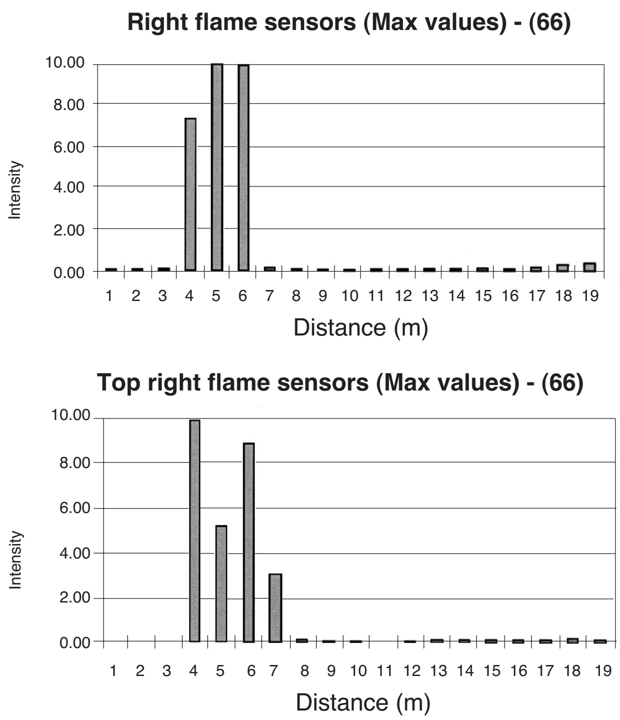

Figure 2—Maximum values (flame sensors) indicating flame extension down the tunnel

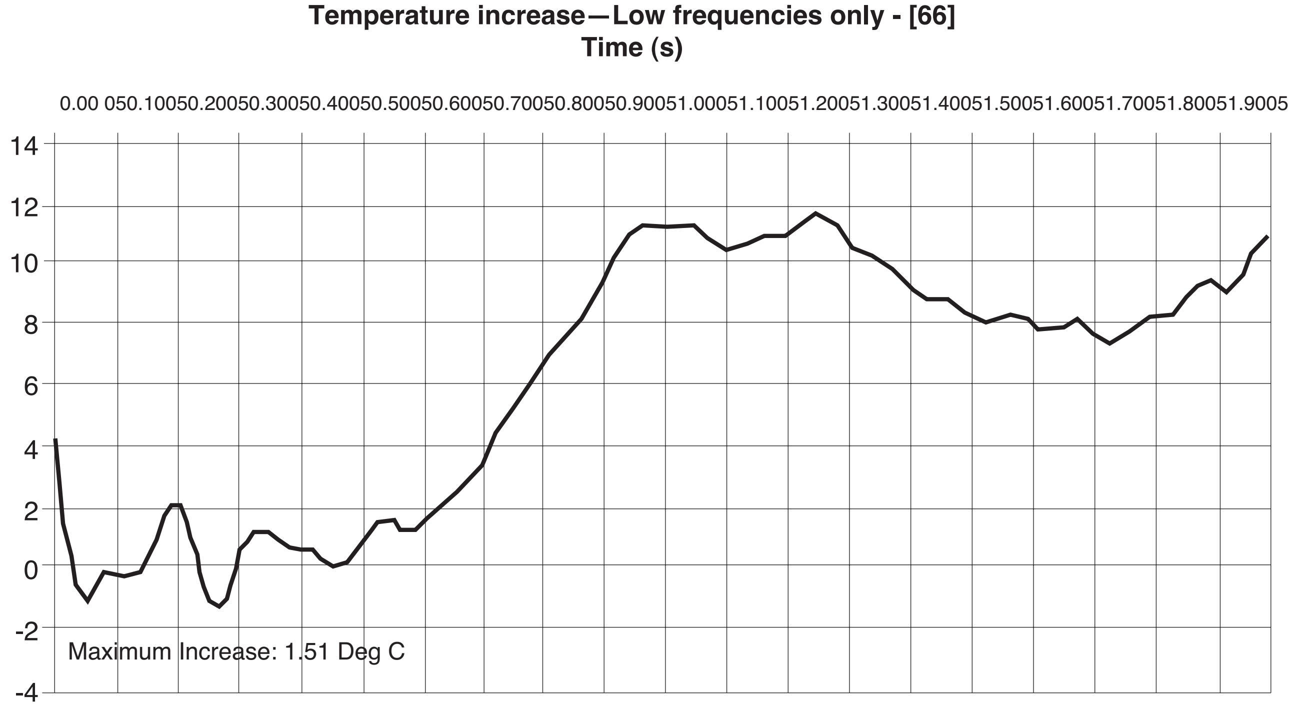

Figure 3—Temperature chart—at the operator's cab

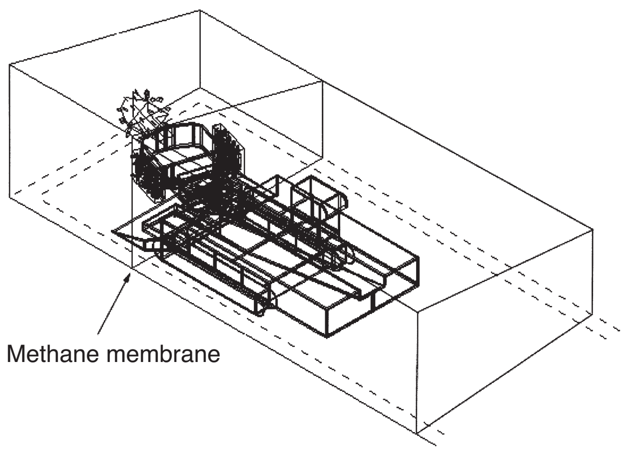

Figure 4—Full-face position

were done for all five sub-conditions. Finally, for the full-face and out-shoulder machine positions, a 12,0% explosion was executed.

It was assumed that the ignition would have been caused by a pick on the machine striking a sandstone inclusion in the coal seam. For the purposes of these tests, a 200-J match head—electrically activated—was placed in the 'shadow' area of the drum (shielded from the ultraviolet sensors of the system). The flame would therefore propagate out from behind the drum before the system detected and extinguished it.

After completion of the 23 tests, including one unsuppressed explosion (test No. 56) for reference, it was decided to repeat the four most difficult tests for absolute confirmation of the configuration. The progression of the flame during the unsuppressed explosion is shown in Figure 7.

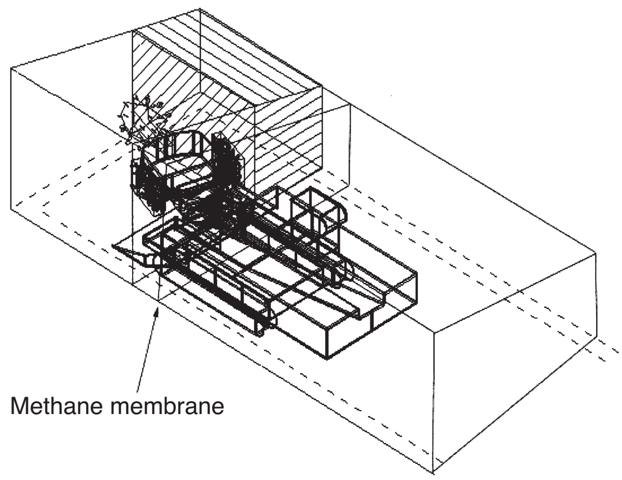

Figure 5—In-shoulder position

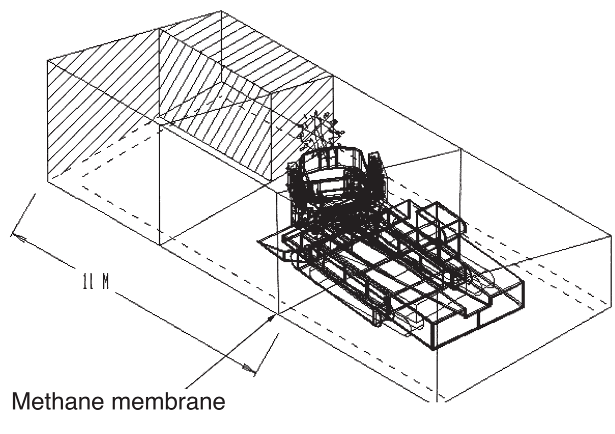

Figure 6—Out-shoulder position

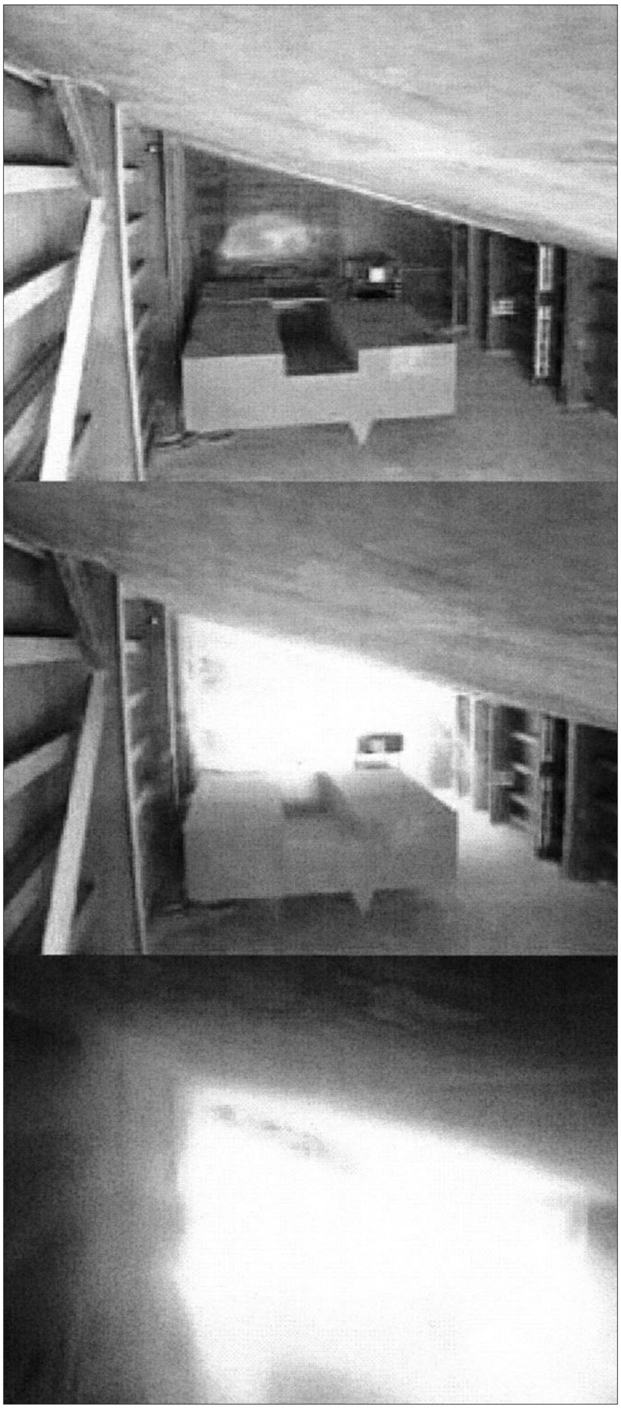

Figure 7—Unsuppressed explosion

After each completed test, the data were analysed to determine whether the explosion had been successfully suppressed in accordance with the protocol.

Results

Full-face tests

A summary of the results of the full-face tests is shown in Table I.

The tests began with the 7,5% methane explosion for full-face conditions (test No. 43). This was successful, with no flame being detected along the right-hand wall of the tunnel (the operator's cab is positioned on the right-hand side of the machine). A small flame was, however, detected at the roof and along the left-hand wall of the tunnel.

After test No. 44, it was decided to increase the amount of suppressant powder and the number of nozzles used. The repeat of test No. 44 (No. 45) was more successful, with the flame running to 6 m but the operator's position remaining safe at 7 m. For all the tests, the pressure increases as a result of the explosion were small. In test No. 49, the flame extended to the operator's position and the temperature increase was also slightly higher than required by the protocol. It was, however, still accepted as being within human tolerance limits. A sequence of photographs of a suppressed explosion is shown in Figure 8.

Table I

Results of full-face tests (operator at 7 m)

Test No.	CH_4/air conc. (%)	Ign. point	Temp. (°C)	P_{Dyn} (mbar)	P_{Dyn} (mbar)	Flame ext. and pos.
43	7,5	BL	6	0,3	11	TLF-5 m
44	9	BL	74	3	21	TLF-8 m
45	9	BL	16	1	19	TRF-6 m
46	9	C	30	5	21	TRF-7 m
47	9	TL	33	6	24	TLF-7 m
48	9	TR	19	7	26	TRF-7 m
49	12	BL	116	7	7	TRF-8 m

In-shoulder tests

Once the full-face tests had been completed, a 4-m shoulder was placed against the right-hand front wall of the tunnel. The machine was moved into the tunnel adjacent to this wall for the in-shoulder tests. The results of these tests are shown in Table II.

All the in-shoulder tests complied with the protocol, with the system successfully suppressing all the explosions at the various ignition (and machine boom) positions.

For this series of tests, the highest temperature measured at the operator's cab was approximately 17°C and, once again, the pressure sensors detected almost no pressure variations due to the explosion. In none of the tests was any flame detected at the operator's cab position.

Out-shoulder tests

For the final series of tests, the machine was moved out of the tunnel to simulate the cutting of the shoulder. A summary of the results is shown in Table III.

In test No. 57, the flame did not reach the operator's position on the right-hand side of the machine but did extend further than this position to the left of the cab. The subsequent 9% explosion (test No. 58) again indicated that the system had come close to failure, with a higher-than-acceptable temperature being measured at the operator's position.

A modification to the HRD configuration (after test No. 61) resulted in the system performing within the limits of the protocol (test No. 62), with no flame detected at the

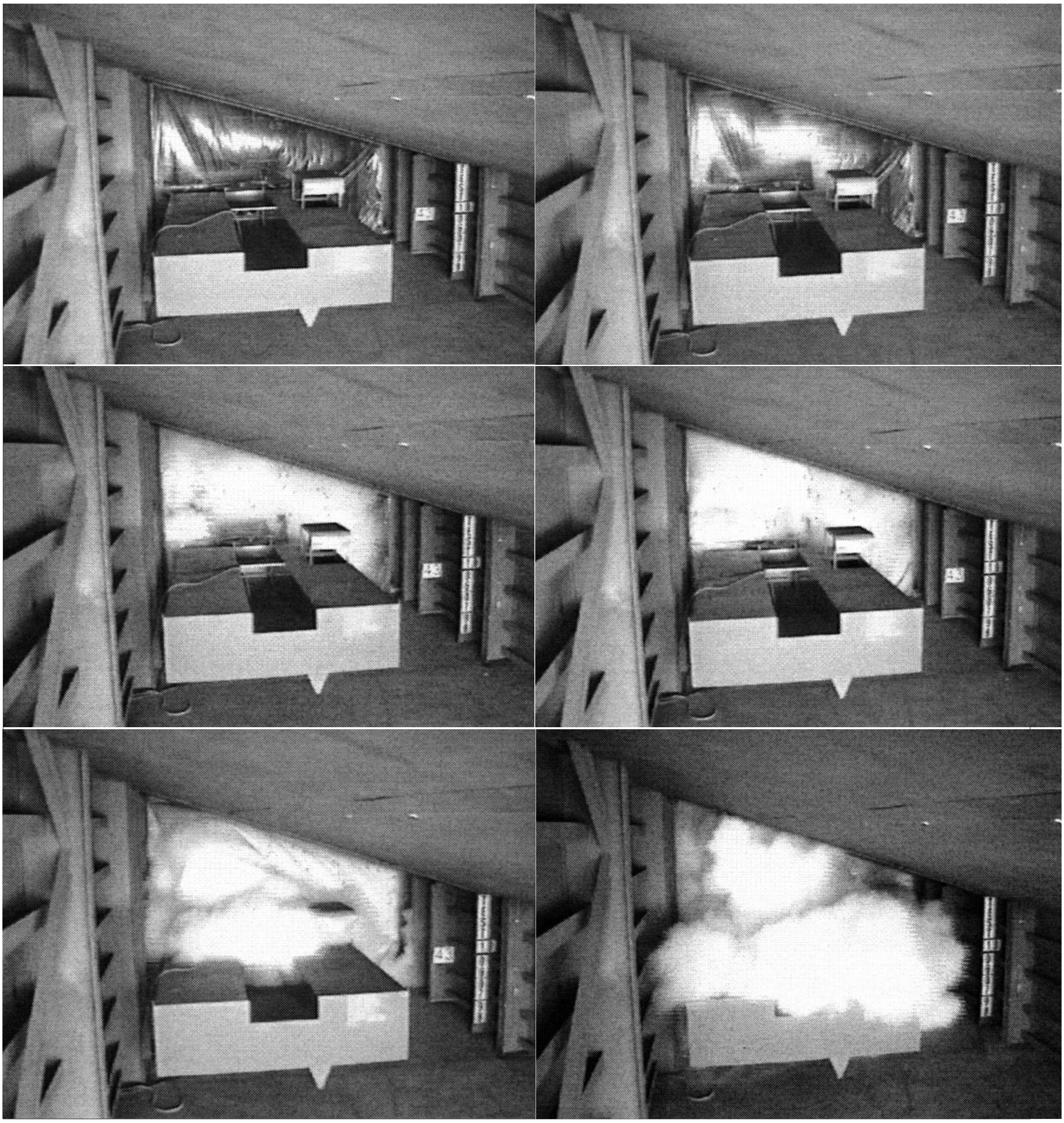

Figure 8—Suppressed explosion—the flame is still visible behind the blanket of powder, but cannot penetrate this blanket

operator's cab and a temperature rise of approximately 25°C.

After this modification had been made, the remaining tests were completed uneventfully at all the given positions and different mixture concentrations for the out-shoulder machine placements. For these tests, the maximum running length of the flame was 11 m (the operator's position was at 11 m for the out-shoulder tests).

Only for the test with the boom positioned at the bottom left of the shoulder was the recorded temperature in the region of 110°C; for the rest of the tests it was well below that temperature. Once again, the pressure sensors detected almost no pressure changes.

In the final testwork (see Table IV), all the tests considered to represent the worst cases before the changes were made to the system were repeated. A marked improvement was seen when the results of the original configuration were compared with those of the final configuration.

Conclusions

With the completion of the tests prescribed by the protocol, the system has proved itself to be effective in detecting and

Table II

Results of in-shoulder tests

Test No.	CH_4/air conc. (%)	Ign. point	Temp. (°C)	P_{Dyn} (mbar)	P_{Dyn} (mbar)	Flame ext. and pos.
50	9	BL	13	2	19	TLF-7 m
51	9	BR	2	3	15	TLF-5 m
52	9	C	15	2	18	TRF-7 m
53	9	TL	17	3	17	TRF-7 m
54	9	TR	3	2	18	TLF-6 m
55	12	BL	2	0,5	4	TRF-5 m

Table III

Results of the out-shoulder tests

Test No.	CH_4/air conc. (%)	Ign. point	Temp. (°C)	P_{Dyn} (mbar)	P_{Dyn} (mbar)	Flame ext. and pos.
57	7,5	BL	24	0,6	9	TLF-12 m
58	9	BL	150	25	79	TLF-11 m
59	9	BR	28	3	26	TRF-9 m
60	9	TR	9	5	2	TRF-9 m
61	9	C	136	3	22	TLF-12 m
62	9	C	25	1	6	TRF-10 m
63	9	BL	110	2	10	TRF-11 m
64	9	TL	86	4	20	TLF-9 m
65	12	BL	19	0,6	8	TRF-7 m

Table IV

Final confirmation tests

Test No.	CH_4/air conc. (%)	Ign. point	Temp. (°C)	P_{Dyn} (mbar)	P_{Dyn} (mbar)	Flame ext. and pos.
66	9	Equivalent to test No. 59	12	4	42	TRF-7 m
67	9	Equivalent to test No. 60	10	1	15	TRF- 7 m
68	9	Equivalent to test No. 50	10	2	22	TLF-7 m
69	9	Equivalent to test No. 44	10	4	35	TLF-7 m

suppressing explosions for the given scenario—configured and mounted on a Dosco 1300H model for an asymmetrical cross-section with an area of approximately 23,3 m^2.

Earlier testing in Germany (Faber, 1990) was confined to a single-cut scenario. The system was subsequently implemented in that country and has proved to be effective in underground applications.

Previously in South Africa the system had proved itself for low-seam conditions, with 9% methane mixture concentration volumes of 80 m^3 to 90 m^3 being used.

To test the Explo-Stop® system for French mining conditions, a second mining cut had to be simulated, resulting in a potential increase in the explosive volume of methane. Furthermore, changes in the symmetry of a cross-section can result in a 9,0% methane/air mixture of up to 180 m^3 in volume. The system complied effectively with all the requirements of the test protocol as stipulated by the French research institute, INERIS, and was deployed in France prior to protect both workers and mines against explosions in these adverse conditions.

Acknowledgements

The authors wish to thank the staff of the Kloppersbos Research Facility for their enthusiasm and participation in the project.

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Slag from testwork on hazardous material arrives safely back in Australia*

Waste material shipped by Australian zinc producer Pasminco to South African minerals researcher Mintek for pyrometallurgical testwork in September, 2000 arrived safely back in Austalia in August this year.

When the material (a 40-ton shipment of paragoethite) was shipped to South Africa a year ago for research purposes, Mintek was accused by various NGOs of contravening the Basel Convention that regulates the transboundary movement of hazardous wastes.

Pasminco operates electrolytic zinc plants in Australia which generate paragoethite, hazardous mainly because of the presence of 2 to 3 per cent lead (Pb) and less than 1 per cent arsenic (As). This material is stockpiled and then treated at another Pasminco plant to recover zinc and generate a non-hazardous slag for final disposal. Depending on the iron content of the feed materials, the pyrometallurgical plant may not have the capacity to treat all the paragoethite generated by Pasminco.

Because of its international reputation for its development work in electric furnaces, including DC-arc smelter technology, and its equally well known rigid adherence to the production of environmentally friendly technologies, Mintek was approached by Pasminco to develop an electric furnace-based process, which would supplement the existing treatment plant, thereby enabling the company to render all of its paragoethite non-hazardous.

In order to accomplish this, samples of the actual material had to be tested in Mintek's in-house pilot plant to obtain critical design parameters and confirm the metallurgical performance of the process. The environmental performance of the process was another key requirement for the test programme.

The pilot plant at Mintek is approximately one-tenth the size of the commercial-scale plant envisaged, and because pyrometallurgical processes require testing at a relatively large scale compared with other processes, it was necessary to ship around 40 tons of paragoethite from Australia to South Africa for this purpose.

At this point, it should be noted that Mintek's policy in all of its research and development projects is that all material tested remain the property of the client, and they are returned to the point of origin after testing. In this particular case, great care had been taken to ensure that relevant permits from both the South African and Australian environmental authorities had been obtained prior to the transport of the material.

During the test programme at Mintek all the environmental and health aspects were carefully monitored, and the work was successfully completed and the objectives met.

According to Mintek's Manager: Pyrometallurgy, Mr Tom Curr: 'These types of waste materials are produced at zinc plants all over the world and constitute serious environmental risk as they are generally stockpiled in tailings dams. A pyrometallurgy process that could successfully treat these wastes, rendering them non-toxic, would greatly reduce the risks inherent in storing these materials. Mintek and Pasminco's joint efforts in this regard should be applauded, as they are contributing materially to sort out this global problem'.

The following is taken from the Official Web Site of the Secretariat of the Basel Convention (www.unep.ch/basel/pub/basics.html):

'During the Next Decade (2000-2010), the...other area of focus will be the minimization of hazardous waste generation. Recognizing that the long-term solution to the stockpiling of hazardous wastes is a reduction in the generation of those wastes—both in terms of quantity and hazardousness—Ministers meeting in December of 1999 set out guidelines for the Convention's activities during the Next Decade, including: active promotion and use of cleaner technologies and production methods; ... A central goal of the Basel Convention is "environmentally sound management (ESM), ... through an integrated life-style approach", which involves strong controls from the generation of a hazardous waste to its storage, transport, treatment, reuse, recycling, recovery and final disposal. ... In the coming decade, more emphasis will be placed on creating partnerships with industry and research institutions to create innovative approaches to ESM'.

According to Mintek's Environmental Specialist, Dr Cobus Kriek: 'The active promotion and use of cleaner technologies and production methods will not be effective, if sample material is not allowed to reach these centres of expertise for research and development purposes, even if they are in developing countries.

'One needs to distinguish between economically developed countries and countries with a sound scientific base. It would seem that the Basel Convention is penalizing countries with a sound scientific base because they are not economically developed. South Africa, however, is a country blessed with a number of global players with strong expertise, including the likes of Sasol, BHP Billiton, Anglo American, Impala Platinum, the CSIR, and many others.

'Mintek, too, is recognized on a global scale as a leader in the field of mineral and metallurgical technologies, which is the very reason that it was sought out by Pasminco for involvement in this project.

'It would seem that the Basal Convention is only allowing developed countries to actively partake in the research and development of "cleaner technologies and production methods". It would also seem that all developing countries are seen to be incompetent with regard to (a) the management of hazardous waste materials, and (b) the research and development of cleaner technologies and production methods. Sustainable development will remain a fuzzy exercise, or goal, when exclusions with regard to participation are made because of generalized perceptions', says Kriek. ◆

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